GEOPHYSICAL INVESTIGATION OF COAL-EXPLORATION DRILLINGS

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SUMMARY

The paper summarizes the physical properties of brown and hard coals, and of their accompanying rocks in Hungary. The knowledge of these parameters, although some overlapping may exist, renders always possible to distinguish coalbearing strata from the sterile layers. Particularly useful results can be achieved by gamma-gamma logging. To prove this fact a few examples are given.

The gamma-gamma procedure offers a possibility to determine the bulk density of the coal in boreholes. The relationship between the density and ash-content gives a possibility to calculate the ash-contents of the coal.

Further on the paper makes an attempt at determining the combination of logging procedures best suited to establish the typical fuel-technical parameters of the coals.

Coal as an organic sediment, considering its composition, physical and chemical properties, belongs to the most complicated mineral raw materials. Its properties are decisively influenced not only by the properties of the originally accumulated organic material, but by the process and conditions of the coalification as well.

The usual subdivision: peat, lignite, brown coal, bituminous coal and anthracite, provides therefore only an approximate delimitation. The physical properties of the structure gradually change throughout the individual coal types.

The typical changes of some parameters are summarized in Figure 1. (Carbon, water-content, resistivity).

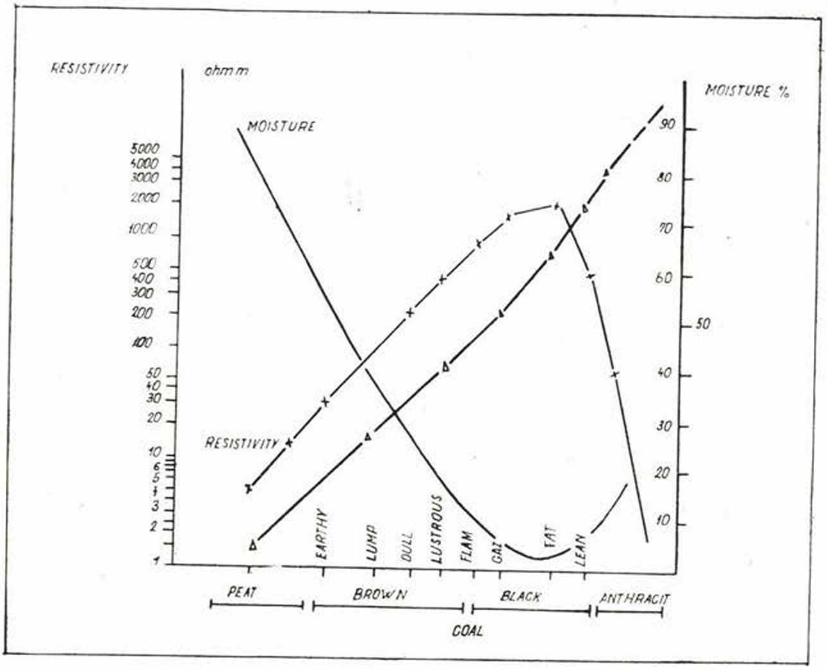
In the geophysical respect the most important effects are the compaction during coalification and the resulting decrease of the moisture-content.

During the coalification the surface of the colloidal parts formed by the association of molecules decreases too (in comparison with the surface of the original compounds) therefore the quantity of adsorbed water also will be less.

The decrease of moisture involves increase of the resistivity of the coal.

Besides the moisture-content the resistivity is determined by the electronic conductivity which becomes ever more important with the progression of coalification. The electronic conductivity is a result of the graphite structure, developed progressively during the coalification.

The resistivity of brown and hard coals is also influenced considerably by the clay-content. This is supposed to form a system of three components:



1. Average trend of some characteristic parameters of coals.

the particles insuring electrolytic conductivity and the ash components are embedded into the non-conductive (or at least poorly conducting) carbonic skeleton.

The relationship is complicated by similar trends of the moisture and ash-content (Table II) indicarting some of the moisture content to be bound to ash-producing components.

The typical parameters of the Hungarian coals and strata traversed by coal drillings are summarized in Table I. It is clear that in most cases several parameters offer the possibility to indicate coal because there is a definite difference between the coal-seams, and other members of the coal series, although some overlapping may be observed in all parameters, except the density.

Only the gamma-gamma method connected with the density of the layers gives an unequivocal indication of coalbearing beds.

Some parameters characterizing the n-radiation measurement (brake-effect, cross-section of capturing, activation) are not included in the mentioned table because in this case the data are not available.

Examining the relationships between logs and series of strata for different areas and coals, only three characteristic types emerge:

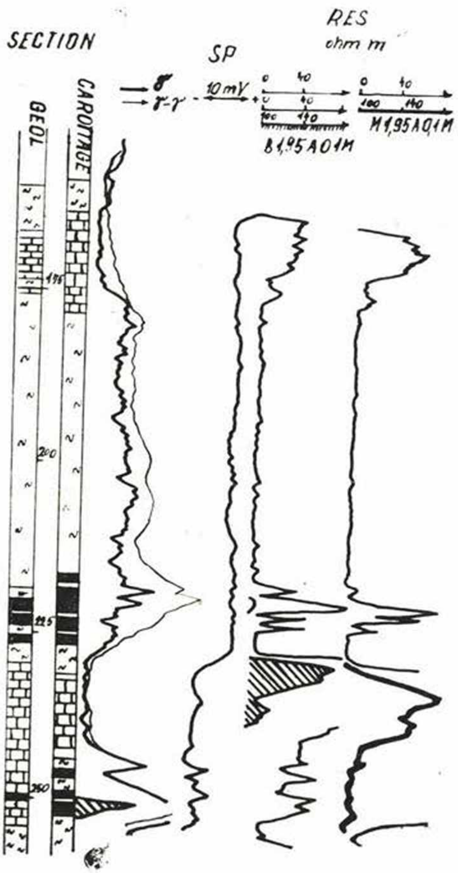
Logs taken in lignite boreholes are shown in figures 2 and 3. The sedimentary complex in both boreholes consists besides the coal seams of alternating sand and clay layers. The resistivity of the deposits does not differ very much

Table I.

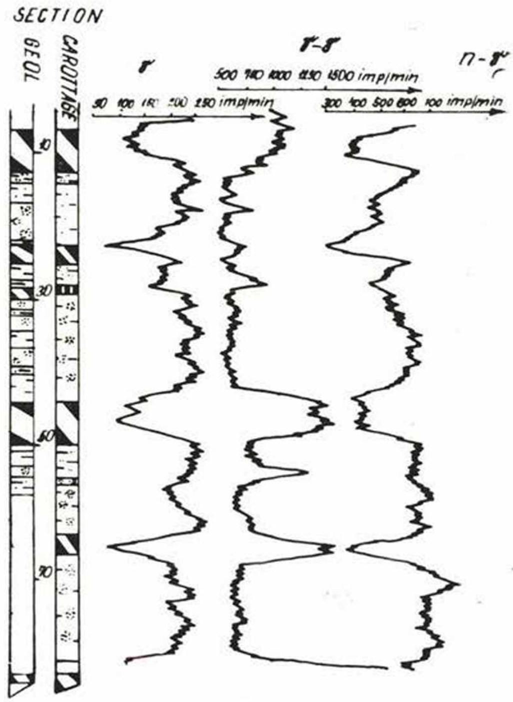
I. Some physical parameters of coals and accompanying rocks in Hungary.

	Resistivity ωm	SP (mV)	Natural γ*	Density g/cm³
Triassic limestones or dolomites ...	600 – 3000	0 – 30	1	2.4 – 2.6
Hard coal, Komló area	200 – 1000	2 – 10	1 – 3	1.2 – 1.7
Sandstone	50 – 500	– 10 – 20	1 – 2	2.2 – 2.6
Trachydolerites	10 – 500	1 – 5	1 – 3	2.5 – 2.9
	(dissolved)			
Phonolite	> 1000			
	(fresh)			
Andesites	> 500	1 – 2	4 – 8	2.4 – 2.8
Clays, slates	1 – 100	0	6 – 10	2.0 – 2.3
Clay marl	100 – 500	0 – 5	4 – 6	2.0 – 2.3
Eocene				
Brown coals:				
Pilis, Dorog, Nagysáp area	60 – 300			
Tatabánya-Oroszlány area	100 – 1200	+ 0 – 20 5 – 10 0 – + 5	1 – 10 12 – 15	1.2 – 1.5
Clays	5 – 30	0	6 – 9	1.7 – 2.2
Sandy clays	10 – 30	– 5 – 10	3 – 7	1.8 – 2.2
Coal-bearing clays	10 – 40	8 – 10	3 – 4	1.6 – 2.0
Limestones	80 – 300	– 5 – 30	2 – 3	1.9 – 2.2
Sandstones	31 – 200	– 10 – 35	2 – 3	2.0 – 2.2
Oligocene				
Tokod – Dorog area brown coals ...	60 – 100	2 – 10	2	1,3 – 1,4
Oroszlány-Majk area brown coals ..	20 – 80	2 – 5	0	1.3 – 1.4
Clays	5 – 25	0	6 – 10	1.7 – 2.0
Sandy clays	5 – 30	2 – 5	3 – 6	1.8 – 2.2
Clayey marl	10 – 30	0 – 2	2 – 4	1.7 – 2.0
Sandstones	20 – 100	– 5 – 10	2	– 2.5
Coal-bearing clays	20 – 50	+ 5 – 10	3 – 5	1.8 – 1.7
Miocene				
Borsod area brown coals	30 – 50	0 – 7	1 – 2	1.2 – 1.6
Nógrád area brown coals	40 – 60	2 – 5	1 – 2	1.2 – 1.6
Várpalota area brown coals	20 – 80	2 – 5	1 – 2	1.2 – 1.3
Clay	2 – 10	0	6 – 10	1.5 – 1.9
Sandy clay	10 – 20	2 – 7	15 – 2	1.7 – 2.2
Clayey marl	2 – 10	0	3 – 4	1.5 – 2.3
Sandstones	150	0 – 3	1	1.9 – 2.50
Coal-bearing clays	10 – 20	0	2 – 3	1.5 – 1.7
Rhyolite tuffs	5 – 50	5 – 20	4 – 6	
Pliocene				
Lignites				
Bükkalja, Mátraalja area	5 – 40	0 – 7	1 – 2	1.1 – 1.3
Torony area......................				
Clay	2 – 10	0	5 – 9	1.5 – 2.0
Sandy clay	10 – 50	– 2 – 7	3 – 6	1.6 – 2.2
Clayey marl	2 – 10	0	4 – 7	1.0 – 2.0

*figures relative to a limestone standard



2. Logs recorded in lignite-drillings in Western-Hungary.

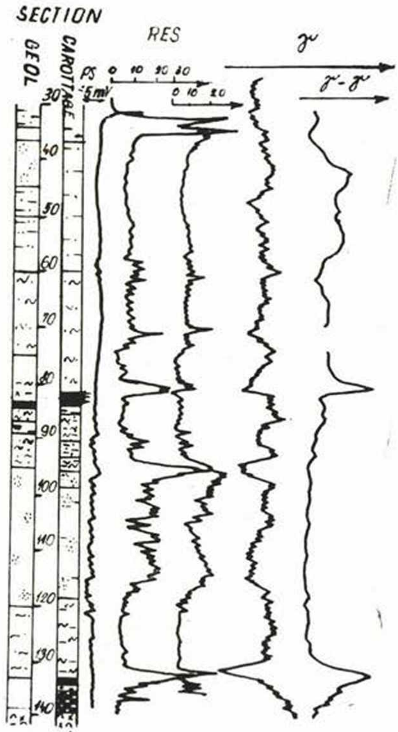


3. Radiation curves in lignite-drillings.

from that of the clay. The indication of the coal deposits is accomplished first of all by the means of radiation curves (natural gamma, gamma-gamma curves). The SP and apparent resistivity curves are used to indicate the sandy members of the sedimentary complex. The neutron-gamma curve (Fig. 3.) is particularly interesting, as it indicates a considerably smaller number of impulses for the lignite deposits than for clays or water-saturated sands. This fact is evidently due to the total H-content of lignites (water + elemental H), being higher than the H-content of other members in the series of layers.

The typical structures of the Borsod coal-field and the corresponding logs are shown in figure 4.

Below the coal deposits rhyolitic-tuffaceous layers occur. Above these layers as reflected in the logs, the seam No. 5. is encountered in the series, having the greatest thickness and a rather heterogeneous composition. This is clear also from the resistivity curves. It is characterized by a minimum on the natu-



4. Electric logs in the sedimentary complex of the Borsod area.

ral gamma-curve, and by a maximum with gradually decreasing values on the gamma-gamma curve.

Seam No. 5. is immediately overlain by a clayey layer of larger thickness, followed by a thick banded sandy clayey complex.

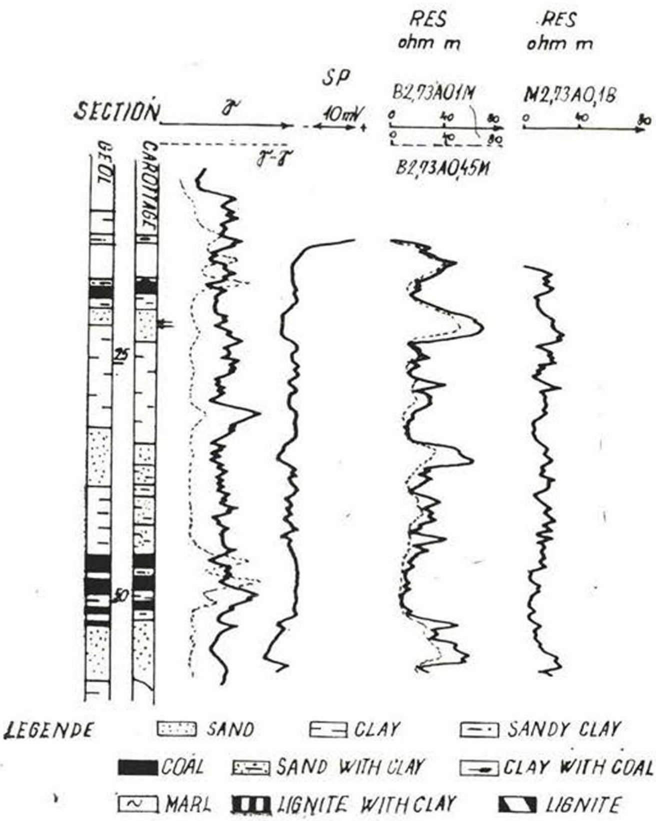
The typical members of the upper part of this complex are represented by two sandy layers (2 – 3 m thick), which can be readily recognized on all records and be used to parallelize the layers. Seam No. 4. is underlain by a clay bed.

Above this seam the sedimentary complex consists of frequently alternating clay and sand strata, being predominantly sandy in the near cover and containing characteristic beds of slightly sandy clay, showing 20 – 30 m thickness higher up in the cover.

In the figure no further deposits of the area are included. The upper part of the series of layers shows a composition characterized by an increasing amount of sand.

The structure of the Eocene brown coal areas in Transdanubia is different from the previous ones.

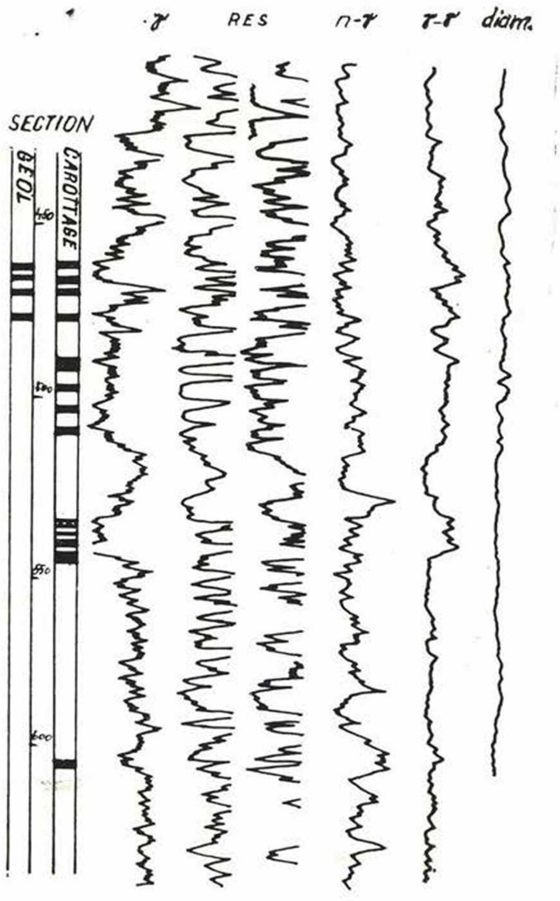
In Figure 5 the dolomite as a deep substratum does not appear because it was not reached by the drilling. The immediate footwall of the lower coal-



5. Logs recorded in a borehole traversing an Eocene coal-deposit.

seam consists of clays. The location of the coal seam can be indicated by means of gamma-gamma curves, but a more exact delimination is rendered possible by the apparent resistivity curves measured with the short potential probe. It is typical of these coal seams that they show a larger natural gamma-activity than the clays. In the cover of the lower seam there is a fresh-water limestone. The bottom of the next seam-group is formed by clay. The depth of the upper seam can be the most successfully determined by resistivity curves. In other properties they are also almost identical with the lower seam.

Above this seam a very thick clayey-marly complex of heterogeneous structure (Molluscan clayey marl) may be found. The next typical member of the series is the Nummulitic limestone belonging already to the middle Eocene.



6. Logs of coal-bearing series of the Mecsek-area.

In the case of hard coals – although the previous statements hold approximately – the situation is more complicated, as a result of the structure of the Mecsek area (Figure 6). In the coal-bearing complex sandstones, clayey-marl and coal-seams alternate with considerably changed properties in the surroundings of trachidolerite intrusions. The delimitation of the coal-seams can be accomplished only by the analyses of SP, resistivity and radioactivity records.

Determination of the Quality of Coals

From the fuel-technical point of view the most important characteristics are as follows:

ash-content
moisture-content, and
calorific value.

The above properties are more or less well-defined by the physical parameters recorded in the boreholes. Between the fuel-technical characteristics a connection is expressed by the S e y l e r formula*)

$$Q = 123{,}9\,C + 388{,}1\,H + 0{,}250\,O_2 - 4269$$

where Q = heat of combustion
C = percentage of carbon content
H = percentage of hydrogen content
O_2 = percentage of oxygen content

The above formula is supplemented by the following relation

$$C\% = 100 - (H_2O\% + \text{ash}\%)$$

The unknown quantities in the above formula are: the percentages of C, H, H_2O and ash.

As a first approximation the determination of oxygen may be omitted since it has a smaller influence upon the value of Q than the other two components.

The determination by geophysical measurements of the four parameters mentioned seems to be possible on the basis of the following considerations.

Determination of ash-content

The measuring of scattered gamma radiation (gamma-gamma intensity) in the borehole offers some possibility to determine the percentage of ash.

In connection with the gamma-gamma activity the relationship between the density and ash content of coals has to be investigated first.

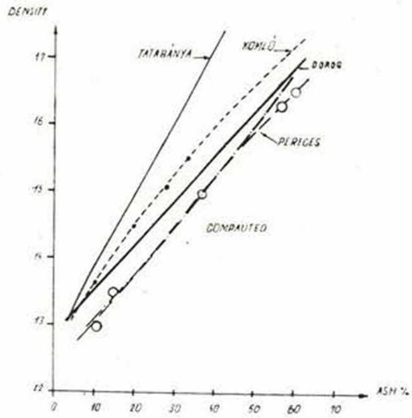
The density of pure carbon is 1,85 gr/cm^3 (that of graphite is 2,25 gr/cm^3), but the density of huminites contained by the majority of browncoals is $1{,}2 - 1{,}35$ gr/cm^3, the density of oxinites contained in a lesser proportion is $1{,}35 - 1{,}55$ gr/cm^3.

* There are several similar formulae in the literature which may be applied with more or less success to the different coal types.

The coal contains, however, ash-forming materials, too, which increase its density, because the density of the ash-forming materials is generally $2{,}0-2{,}5$ gr/cm^3.

In Hungary from the view-point of ash-composition the brown coals can be divided in principle into a carbonatic type and a silicatic type. According to our investigations the difference between these two types is small since their density shows only a small fluctuation.

The density of coal increases with the increasing ash-content. The relationship is shown in Figure 7. In the theoretical curve for the density of ash-free coal 1,26 gr/cm^3 while for the average density of ash-forming materials 2,2 gr/cm^3 was used. The figure represents the result of laboratory measurements, performed on different coal-samples and some data obtained from the Coal Mining Trusts. The theoretical curve is in good agreement with the observed data.



7. Average ash-content and specific gravity of coals of some Hungarian coal-deposit areas.

The colloid-gel has a considerable porosity, corresponding to its nature. Therefore the density of coal differs considerably from that of the coal-forming materials.

It is known from the gamma-gamma measurements that the intensity of the scattered radiation may be expressed as a function of the parameters of the material by the following empirical formula

$$I = \frac{A}{L}\varrho e^{-k\varrho l}$$

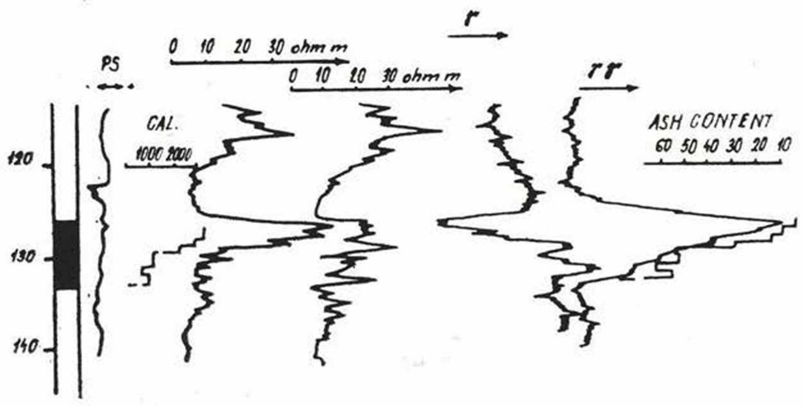
where ϱ denotes the density; l is the length of the probe, k is the absorption coefficient, estimated at $\approx$ 0,06 cm^3/gr for common rocks and for steel-covered probes.

However the sample contains not only the atoms of the coal components, but the atoms of its water content too. Therefore the effective density in the gamma-gamma measurements shows the following relation to the true density of coal:

$$\varrho = (1-\varphi)\,\varrho_{\text{coal}} + \varphi$$

where ϱ is the density determined by gamma-gamma measurement, ϱ_{coal} is the density of coal, φ is the value expressing the water-content, i. e. porosity.

It has been shown previously, that the ash-content of coal is proportional to its density. However, there exists no direct relationship between the ash-content of the coal and the gamma-gamma radiation intensity observed in the borehole, as the gamma-gamma intensity varies with the changing porosity of the coal even in the case of a constant ash-content. In practice as a first approximation, however, the porosity may be assumed to be constant and so the variation of gamma-gamma intensity can be regarded as a change in ash-content. A corresponding relationship is shown in Figure 8., as a result of our measurements in the Borsod-area.



8. Distribution of gamma-gamma anomalies and ash-content of coals in a borehole of the Borsod area.

It can be established from the figure, that the resolving ability of the measurement must be increased in order to apply this method to the investigaton of thinner layers.

Determination of moisture-content

To the moisture-content determination of coals the measurement of neutron-gamma radiation appears to be suitable.

In the composition of coals the moisture-content takes an important role especially at low and medium coalification. This is shown in Figure 1 and more clearly in Table II., where the moisture-content of the different coal-types is given in terms of weight-percents. The table contains also the H contents of the moisture and of ash-free coal. This H content gives the typical cross-section affecting the braking and capture of neutrons. The importance of H content becomes conspicuous only in the case of brown coals.

Table II.

II. Composition of huminitic coals.

	C	Composition of elements. %		Calorific value Cal.	Original moisture content %
		H	O+H		
Peat	55	6	39	5000	80 – 90
Earthy brown coal	65	5	30	6000	40 – 60
Lump brown coal	70	5	25	6200	30 – 40
Dull brown coal	74	5	21	6800	15 – 30
Subbituminous coal	78	5	17	7400	8 – 15
Flame coal	80	5	15	7600	4 – 10
Gas coal	84	5	11	8000	3 – 4
Fat coal	88	5	7	8500	2
Lean coal	92	4	4	8700	1
Anthracite	95	3	2	8500	2 – 3
Graphite	100	–	–	7860	–

The role of the carbon and the ash-forming materials can be neglected in the cross-section of braking and capture of coals because their atomic cross-section is smaller by orders of magnitude than that of the hydrogen, as it may be seen in Table III.

The results of the computation of the capture cross-section of lignites and brown coals are as follows.

Table III.

III. Neutron-capture cross-section of the main components of lignites and brown coals.

Composition of coals in terms of atomic %	C	H	O	S	Ag	Si
Brown coal (Sajó Valley)	27.4	47.8	22.2	0.91	1.14	1.26
Cross-section	0.0013	0.1404	–	0.046	0.0026	0.0016
Lignite	21.46	53.2	20.85	0.69	0.72	1.08
Capture cross-section	0.0011	0.1596	–	0.3034	0.016	0.014

Accarding to the same calculations the capture cross-section of a pure quartz-sand of 40 percent porosity, saturated with fresh water amounts to 0,105.

A similar calculation of macroscopic capture cross-section and of braking make directly evident the fact demonstrated in Figure 3., that brown coals show essentially a greater neutron-gamma minimum than the sands.

The moisture-content decreases rapidly with the coalification resulting in the decrease of the neutron-braking and of the capture cross-section. Hence at a higher degree of coalification the neutron-gamma anomalies of coals may change sign relative to the sands.

At the same time the data show the total capture cross-section of coal components (except of S in some cases) to be smaller by one order of magnitude than the cross-section of H. The same is true for the braking cross-section. Thus the total H content of coals may be determined by the neutron-gamma curves. (The disturbing effect of Cl, of very considerable capture cross-section, has a smaller importance than in oil exploration, because the occurring NaCl concentrations are much lower.

The computation of the moisture-content in the knowledge of the total H content requires the determination of the elemental H.

To determine the elemental H-content, in a first approximation the regional average can be taken, its variation being small. A more exact determination is offered by the gamma-gamma logging as the H content and density show a close connection.

The moisture content of coals may be determined in principle also by the resistivity. The relationships become, however, more complicated, especially in the case of brown coals, as a result of clay and absorbed water-content.

In further research the neutron-neutron method offers new possibilities, giving the H content completely free of all other disturbing factors.

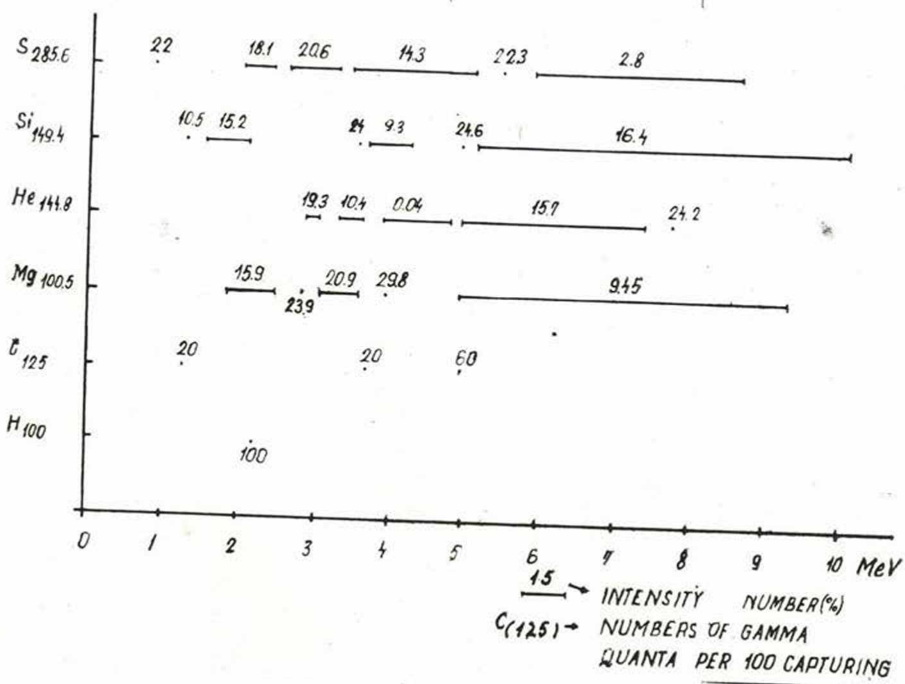
The investigation of gamma-spectra resulting from the radiation of captured thermal neutrons suggests a new possibility for the direct detection of the carbon content, since the gamma-radiation of carbon can be definitely distinguished from that due to the neutron capture of H-nuclei, as can be seen in Table IV. The table summarizes the spectra of neutron capture radiation of the most important ash-components. For a better understanding, these data are represented in Figure 9. The method seems to be suited to distinguish the effect of H from the other constituents. The spectrum bands of the ash-forming constituents tend to overlap wherefore their separation seems to be a difficult task.

The mentioned relationships offer a possibility to determine the characteristic parameters of coal by logging-methods. The practical realization depends very much on the accuracy of the performed measurement, and on the problem as to whether the measurements can be freed from the effects of the boreholes.

Table IV.

IV. Spectra of the main components of neutron-capture radiation of coal.

Elements	Number of gamma quanta per 100 captures	Energy of gamma quanta neV	Relative intensity of the components. %
H	100	2.23	100
C	125	4.95	60
		3.68	20
		1.26	20
Al	144.5	7.72	24.2
		4.94 – 7.34	15.7
		3.88 – 4.79	3.04
		3.29 – 362	10.4
		1.84 – 3.02	19.3
Si	149.4	5.12 – 10.6	16.4
		4.93	24.6
		3.67 – 4.3	9.3
		3.55	24.0
		1.5 – 2.1	14.2
		1.28	10.5
Ca	144	8.37	20.2
		6.4	16
		4.86 – 5.9	8
		2.00 – 4.42	26.8
		1.94	27
		0.46 – 1.84	22.2



9. Spectra of the main components of neutron-capture radiation of coa s.

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